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The Analysis of Equivalence Classes

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14. ABSTRACT *(Maximum 200 words)*:

Many essential skills required of military personnel involve responding in the same manner to cues that are perceptually different. One example of such a set of cues would be the representations of an airplane produced by visual sighting, radar, infrared detection, and IFF, or acoustic signature. Another example would be the topographical map representation, the visual image, and the orienteering symbol for a given terrain feature, such as a mountain. Perceptually different cues that have become interchangeable are said to form an equivalence class. Recognizing the interchangeability of the representations in the airplane set is critical if one is to react appropriately to an airplane in battlefield conditions; recognizing the interchangeability of the representations in the terrain set is critical if one is to navigate appropriately from a map. In addition, because the cues experienced in training will resemble but will not be identical to the cues encountered in the field, it is also critical for individuals to generalize from the cues in training to the cues in the field.

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BACKGROUND. Many essential skills required of military personnel involve responding in the same manner to cues that are perceptually different. One example of such a set of cues would be the representations of an airplane produced by visual sighting, radar, infrared detection, and IFF, or acoustic signature. Another example would be the topographical map representation, the visual image, and the orienteering symbol for a given terrain feature, such as a mountain. Perceptually different cues that have become interchangeable are said to form an equivalence class.

Recognizing the interchangeability of the representations in the airplane set is critical if one is to react appropriately to an airplane in battlefield conditions; recognizing the interchangeability of the representations in the terrain set is critical if one is to navigate appropriately from a map. In addition, because the cues experienced in training will resemble but will not be identical to the cues encountered in the field, it is also critical for individuals to generalize from the cues in training to the cues in the field.

Errors in target identification or the inability to navigate from a map can have disastrous consequences. Such errors may reflect flaws in the formation of task-relevant equivalence classes, flaws in the relatedness of the members of the underlying equivalence class, flaws in the response-evoking properties of the class members, and/or inappropriate generalizations between the cues used for training and the events encountered in the field. The consequences of such errors emphasize the importance of understanding how equivalence classes can be reliably established, how the structure of equivalence classes influence the cohesiveness and relatedness of the class members, and how the members of an equivalence class generalize to other similar stimuli.

With the advent of the digital battlefield, the volume of information about military targets that will be displayed in symbolic forms will far exceed that currently provided to military personnel. In the foreseeable future, military personnel will have to learn many more equivalence classes than are now required of them. Clearly, then, a thorough understanding of equivalence classes will play an increasingly important role in the education and training of military personnel. Given the current downsizing of government, fewer resources will be available for training while a greater training and instructional load will be needed to prepare well trained military personnel. Thus, a full understanding of the factors that can increase the efficiency with which individuals can learn militarily relevant equivalence classes would be of substantial value.

CONTRACT GOALS. The purpose of the contract, The Analysis of Equivalence Classes, was (a) to identify variables that enhance the likelihood and efficiency of equivalence class formation, (b) to determine how the structure of equivalence classes influence their cohesiveness and the relatedness of their members, and (c) to determine how behaviors occasioned by the members of equivalence classes generalize to other cues that resemble class members. At the beginning of the contract period, relatively little was known about these processes. These processes have been clarified by the research supported by the contract. **The results of the research have been reported in 17 articles published in peer-reviewed professional journals, and have been presented in 55 papers presented at university colloquia or professional conferences.** In addition, 7 more manuscripts are currently being prepared for submission to peer-reviewed journals. Findings in each of the three abovementioned areas of investigation are presented in the following sections.

SUMMARY OF RESULTS

RELATEDNESS OF STIMULI IN EQUIVALENCE CLASSES. It has been generally assumed that all stimuli in an equivalence class are interchangeable. That position was questioned by us in two influential theoretical articles (Fields, Verhave, & Fath, 1984; Fields & Verhave, 1987). In those papers we proposed that the specific relations that are trained as the prerequisites of an equivalence class also define the relatedness of the stimuli in the class; the relatedness of any two stimuli in an equivalence class should be an inverse function of the number of nodal stimuli that separate the two stimuli in question. This is called the nodal distance effect. How can the nodal distance effect be measured? How can stimuli in an equivalence class be both interchangeable and not interchangeable?

While this theory has been controversial, experiments conducted in many laboratories including my own have made observations that confirmed the theory. The nodal distance that separates the stimuli in a class influences a wide range of test performances, which include the order of emergence of derived relations, transfer of responding among stimuli in a class, reaction times occasioned by class members, and generalization to new stimuli that resemble class members. Most recently, we found that the nodal structure of previously learned equivalence classes influences an individual's ability to learn new equivalence classes. Finally, our experiments have identified the factor that is responsible for making the stimuli in an equivalence class function either interchangeably or noninterchangeably. In the course of these studies, we also developed a new method of measuring the relational control of responding. That mode of analysis permitted us to obtain unequivocal measures of relational responding acquired by stimulus relations in general, and the effects of nodal distance specifically. Thus, the empirical exploration of a variable defined in theory has been shown to influence a wide range of equivalence-class based performances, and has also led to a better understanding of the conditions under which stimuli in equivalence classes can be substituted for each other. This information can be used to enhance predictions of performances that should be based on equivalence class membership in real world settings and would be of military relevance.

The theoretical analysis presented by Fields and Verhave (1987) also proposed that a second structural variable, directionality of training, should also influence equivalence class formation. Research by others showed that directionality of training influenced class formation with young children, but it did not appear to influence equivalence class formation by adults. The results of research in my laboratory showed that the effect of directionality of training on equivalence class formation by adults is substantial and interacts with the size of the classes being learned and the training and testing procedures used to establish the classes. These results identified factors that interact with directionality of training to control equivalence class formation, and disclosed the generality of the effects of directionality of training on equivalence class formation. This information has practical utility since it can be used to guide the selection of conditions that will optimize the learning of equivalence classes that are of military relevance. These results are also fo theoretical significance because they show that the effects of directionality of training are not developmentally constrained.

ENHANCEMENT OF EQUIVALENCE CLASS FORMATION. In most laboratory-based studies of equivalence class formation, training and testing has been conducted using matching to sample procedures. If equivalence classes can be established using only one mode of training and testing, the practical utility of establishing equivalence classes in real world settings would be limited. Research in my laboratory has shown that equivalence classes can be established under a broad range of training and testing conditions. Specifically, we showed that stimulus-pairing yes-no procedures can be used to establish and expand equivalence classes. In

addition, we showed that discrimination training and stimulus fading could be used to expand class size. These results suggest that task-relevant equivalence classes can be established in real-world settings by use of a variety of training and testing protocols.

Prior to 1990, equivalence classes were established by use of one serial order of training and testing, called the complex to simple protocol. This protocol resulted in about 70% of subjects forming equivalence classes. An analysis of that protocol showed that many tests were conducted before all prerequisites had been demonstrated. We developed an alternative procedure called the simple to complex protocol that established all prerequisites before conducting the critical tests used to demonstrate the emergence of equivalence classes; that protocol results in class formation by 93% of subjects. The use of the simple to complex protocol has substantial applied value when the instructional goal is to insure the formation of equivalence classes by large numbers of trainees.

Of the subjects who fail to form equivalence classes under the simple to complex protocol, all of the failures occur on tests of transitivity. While resistant to remediation, we finally solved the problem. A multiple exemplar concept formation approach led to the emergence of successful transitivity performances by 85% of the subjects whoi had previously failed transitivity tests. Once remediated, all subjects then formed equivalence classes. When incorporated into the simple to complex protocol, then, exceptionally reliable equivalence class formation was assured for 98% of subjects.

Much human learning occurs under conditions of massed training and massed testing due to pressures of time and personnel. Under laboratory conditions that simulate these circumstances, likelihood of equivalence class formation is very low. That percentage can be raised dramatically (15% to 85%) by prior training of classes using the STC protocol. The time spent enables individuals to learn under poor learning conditions. Two studies have determined that both the size and the nodal structure of previously learned classes each influence the learning of new classes under the simultaneous protocol. Unexpectedly, the nodal structure is responsible for more of the enhancement effect than the size of the previously learned classes. These variables also influence the cohesiveness of stimuli in the newly learned classes. It is clear that the prior training of equivalence classes increased the amount of instructional time spent for each individual. Conversly, this pretraining greatly increased the percentage of subjects who subsequently learned new classes. Therefore, the additional training time increased by a factor of 6-to-1 the efficiency of overall instructional time. Pretraining minimized the instructional resources needed to achieve efficient learning of equivalence classes by large groups of trainees. All of these findings will lead to the development of superior training technologies that can be used to prepare troops to learn new materials under training conditions that are less than optimal.

Finally, we found that the likelihood of equivalence class formation is influenced by the temporal separation of stimuli that become related during training. The results of that experiment have important implications for the training conditions that can optimize equivalence class formation, and also have important implications for a general reinterpretation of the processes that are involved in the formation of equivalence classes.

EXTENSION OF EQUIVALENCE CLASSES BY GENERALIZATION and CONTEXT. Equivalence classes consist of stimuli that are perceptually disparate. In real world settings, however, the members of an equivalence class must resemble other objects in the environment. For example, while a picture of a tank is a member of an equivalence class, the tank will be seen from many different vantage points in a field settings. It is important for these novel views of the tank to call forth all of the information that belongs to the tank-based equivalence class that had been learned during training. That is, the members of an equivalence class must generalize to other

related stimuli for the equivalence-class-based information to be of practical value. It is also crucial that the new views of the tank call forth the actions learned in training; that is, responses trained to one member of an equivalence class should transfer to new stimuli that are variants of a member of an equivalence class. These processes had not been explored prior to the contract.

We began the exploration of these processes in 1991 by developing a procedure to assess the extension of equivalence classes by generalization. We then identified a number of variables that influenced the range of new stimuli to which equivalence class members will generalize. We also demonstrated that a specific response trained to occur to one member of an equivalence class will transfer to new stimuli that resemble another member of the equivalence class. Both of these effects could be predicted by prior knowledge of the perceived similarity of stimuli before some of them became members of equivalence classes. In another study, we found that generalization of equivalence class membership also occurs across sensory modalities.

A given stimulus can function as a member of more than one class. For example, the word shell can be a member of the class of weapons, or the class of objects found at the seashore. The stimuli to which the term is related will be controlled by other contextual stimuli. We demonstrated how the control of class membership can be established by contextual stimuli and how that contextual control can generalize to to new cues that resemble the contextual stimuli.

On the practical level, the results suggest procedures that can be used to enhance the transfer of information learned in training to actual field settings. On the theoretical level, the procedures that influence the formation and extension of equivalence classes by generalization can be used to account for the development of naturally occurring categories.

SUMMARY. On a practical level, the cumulative effects of the research that was supported by the contract can be used to develop superior instructional technologies for teaching equivalence classes of military relevance to Army personnel. On a theoretical level, the results of many of these experiments have clarified, extended and reshaped our understanding of the processes involved in the formation of equivalence classes, a form of stimulus class that directs large segments of complex human behavior.

PRODUCTIVITY DURING THE CONTRACT PERIOD

PUBLICATIONS

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ON STIMULUS RELATEDNESS IN EQUIVALENCE CLASSES

Published

Fields, L., Landon-Jimenez, D.V. Buffington, & Adams, B.J. (1995). Maintained nodal distance effects after equivalence class formation. Journal of the Experimental Analysis of Behavior, 64, 129-146.

Fields, L., Adams, B.J., & Verhave, T. (1993). The effects of equivalence class structure on test performances. The Psychological Record, 43, 697-713.

Fields, L., Adams, B.J., Verhave, T., & Newman, S. (1993). Are stimuli in equivalence classes equally related to each other? The Psychological Record, 45, 85-105.

Submitted

Fields, L. (submitted). The behavioral kernel: the appropriate unit of analysis for the measurement of relational responding. Journal of the Experimental Analysis of Behavior.

In preparation

Varelas, A., & Fields, L. Nodal distance effects in the absence of equivalence class formation.

ON ENHANCEMENT OF EQUIVALENCE CLASS FORMATION

Published

Buffington, D.M., Fields, L., Adams, B.J., & Landon-Jimenez, D.V. (in press). Enhancing the formation of equivalence classes under simultaneous training and testing conditions. The Psychological Record.

Fields, L. (1996). The evidence for naming as a cause or facilitator of equivalence class formation. Journal of the Experimental Analysis of Behavior, 65, 279-282.

Adams, B.J., Fields, L., & Verhave, T. (1993a). Effects of test order on intersubject variability during equivalence class formation. The Psychological Record, 43, 133-152.

Fields, L., Newman, S., Adams, B.J., & Verhave, T. (1992). The expansion of equivalence classes by simple discrimination training and stimulus fading. The Psychological Record, 42, 3-15.

Fields, L., Adams, B.J., Newman, S., & Verhave, T. (1992). Interactions of emergent relations during the formation of equivalence classes. The Quarterly Journal of Experimental Psychology, 45B, 125-138.

Submitted

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Fields, L., Reeve, K.F., Varelas, A., Rosen, D., & Belanich, J. (submitted) Equivalence class formation by stimulus pair/yes-no procedures. Submitted to the Journal of the Experimental Analysis of Behavior.

In Preparation

Adams, B.J., & Fields, L. Effects of delayed matching to sample on equivalence class formation.

Adams, B.J., & Fields, L., Equivalence classes formed by multiple negative comparison training with no reinforcement.

Fields, L., & Rosen, D. Remediating transitivity failures by multiple exemplar training.

Fields, L., & Hobbie, S. Effects of MTO and OTM training clusters on equivalence class formation.

ON THE EXTENSION OF EQUIVALENCE CLASSES BY GENERALIZATION

Fields, L., Brown, J.L., Adams, B.J., and Verhave, T. (accepted). Predicting the generalization of emergent relations from primary generalization. Journal of the Experimental Analysis of Behavior Fields, L., Adams,

Buffington, D.M., Yang, W., Adams, B.J., & Verhave, T. (in press). Response transfer between stimuli in generalized equivalence classes. The Psychological Record.

Adams, B.J., Fields, L., & Verhave, T. (1993b). The formation of generalized equivalence classes. The Psychological Record, 43, 553-566.

Fields, L., Adams, B.J., Brown, J.L., & Verhave, T. (1993). The generalization of emergent relations in equivalence classes: Stimulus substitutability. The Psychological Record, 43, 235-254.

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In preparation

Belanich, J., & Fields, L. The formation of tactile equivalence classes.

Adams, B.J., & Fields, L. Pretraining effects on stimulus interchangeability in generalization tests of equivalence.

ON EQUIVALENCE CLASS FORMATION IN GENERAL

Fields, L., & Nevin, J.A.(1993). Special Issue on Stimulus Equivalence, The Psychological Record, 43(4), 543-841.

Fields, L. (1993). Foreword. The Psychological Record, 43, 543-546.

Fields, L. (in press). Preface. In J. Leslie Principles of Behavioral Analysis (3rd Ed.).

CONFERENCE ORGANIZATION

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The Fifteenth Symposium on Quantitative Analyses of Behavior: Stimulus Relations. (1992), with M.L. Commons, J.A. Nevin, and M. Sidman.

INVITED ADDRESSES OR PAPERS PRESENTED AT CONFERENCES OR COLLOQUIA

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INTERNATIONAL

Fields, L. (1995). The effects of structural variables on the relatedness of stimuli in equivalence classes. An invited address presented at University College Cork, Cork, Ireland, April 20, 1995.

Fields, L. (1995). The steady state effects of nodal distance on the relatedness of stimuli in equivalence classes. An invited address presented at the University of Liverpool, Liverpool, Great Britain, April 13, 1995.

Fields, L. (1995). Two parameters of pretrained equivalence classes that enhance the formation of new equivalence classes established through simultaneous training and testing, presented at the 1995 Conference of the Experimental Analysis of Behavior Group, London, England, April 10-12.

Fields, L. (1994). Methodological enhancements of equivalence class formation. An address included in the symposium, Stimulus equivalence in infants, presented at the 1994 Annual Convention of the International Conference on Infant Studies, Paris, France, June 2-5.

Fields, L. (1994). Enhancing the formation of equivalence classes established through simultaneous training and testing. An address included in the symposium, The origins of stimulus equivalence, presented at the 1994 Annual Convention of the Great Britain Experimental Analysis of Behavior Group, London, England, April 13-15.

Fields, L. (1992). The concept of an extended equivalence class and the analysis of complex human behavior. An invited address presented at the University Sao Paulo, Sao Paulo, Brazil, April 27, 1992.

Fields, L. (1992). The extension of equivalence classes by primary generalization. An invited address presented at the University Sao Carlos, Sao Carlos, Brazil, April 28, 1992.

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Fields, L. (1992). Extending equivalence classes by category merger or discriminability. An invited address presented at the Experimental Analysis of Behavior Easter Conference, University College, London, March 30- April 1, London, England.

Fields, L. (1991). Synthesizing natural categories from equivalence classes and primary generalization. An invited address presented at the Experimental Analysis of Behavior Easter Conference, University College, London, April 3-5, London, England.

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Fields, L., Rosen, D., Reeve, K.F., Hobbie, S., Varelas, A., & Adams, B.J. (1995). Nodal distance effects in emergent relations test performances that do and do not show equivalence class formation. A paper presented in the symposium, Influencing and measuring equivalence class formation, presented at the 1995 Annual Convention of the Association for Behavior Analysis, Washington, DC, May 28.

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Fields, L. (1994). Transfer of responding in generalized equivalence classes. An address included in the panel discussion, Stimulus equivalence, fluency, and generative instruction: Same puzzle, different pieces? presented at the 1994 Annual Convention of the Association for Behavior Analysis, Atlanta GA, May 25-30.

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REVIEWER OF MANUSCRIPTS FOR JOURNALS

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